BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Preliminary Sizing of a Mars Excursion Module Ascent Capsule Based on Mercury Spacecraft Design - Case 233

DATE: September 25, 1967

FROM: M. H. Skeer

MEMORANDUM FOR FILE

INTRODUCTION

High ΔV's and multiple stagings required to perform complex Mars landing and return maneuvers make gross Mars Excursion Module (MEM) weight extremely sensitive to the weight of its ascent (surface to orbit) capsule. It is apparent from simple growth factor examinations that, as a result of cascading staging penalties, the ascent payload weight is singularly the overwhelming factor governing gross MEM weight. Achieving a minimum weight ascent stage is, therefore, tantamount to achieving a minimum weight (and cost) manned Mars landing mission.

In this memorandum a preliminary sizing estimate of a MEM ascent stage (MEM/AS) is undertaken with the purpose of obtaining a rational estimate of minimum useful ascent payload weight. The Mercury spacecraft is used as a scaling reference since its simplicity of design and operation are most consistent with the spacecraft concept considered here (schematically shown in Figures 1-3).

Mercury was an austere system designed as an experimental spacecraft to accomplish relatively limited tasks with specific operational objectives. Unlike Gemini and Apollo, Mercury was not strapped with penalties inherent in vehicles designed for high utilization goals to accommodate a variety of systems and missions. The advantages of employing Mercury as a scaling tool are, however, compromised by outmoded (1959) subsystem technology which without careful scrutiny, could result in excessive subsystem weight estimates.

In support of this study D. E. Cassidy and the author visited McDonnell Aircraft (prime spacecraft contractor) to discuss detailed aspects of the Mercury design. This was principally to gain an understanding of the significant factors contributing to Mercury subsystem weights, and to ascertain in view of succeeding events and advances in the state-of-the-art, if these weights did indeed represent a valid measure for scaling purpose

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ABSTRACT

High ΔV's and multiple stagings required to perform complex Mars landing and return maneuvers make gross Mars Excursion Module (MEM) weight extremely sensitive to the weight of its ascent (surface to orbit) capsule. It is apparent from simple growth factor examinations that, as a result of cascading staging penalties, the ascent payload weight is singularly the overwhelming factor governing gross MEM weight. Achieving a minimum weight ascent capsule is, therefore, tantamount to achieving a minimum weight (and cost) manned Mars landing mission.

In this memorandum a preliminary sizing estimate of a MEM ascent capsule is undertaken with the purpose of obtaining a rational estimate of minimum useful ascent payload weight. The Mercury spacecraft is used as a scaling reference since its simplicity of design and operation are most consistent with the spacecraft concept considered here.

It is concluded that upon elimination of those Mercury design constraints not consistent with a Mars ascent capsule mission profile (i.e., reentry, surface launch abort capability, and life support redundancy) the weight of a "derivative" Mercury spacecraft would be reduced from 4,600 lbs (at launch) to under 800 lbs. Advances beyond the current state-of-the-art were not included to achieve these reductions. Employment of advanced systems coupled with refinements in operational procedure would undoubtedly result in further substantial weight reductions.

Some of the more important implications of these results are:

1. One-man MEM ascent capsule weight seems to be compatible with MSSR (Mars Surface Sample Return) launch capability to a highly elliptical capture orbit, and,

2. A two-man MEM of less than 35,000 lbs gross weight appears to be feasible.

In the main body of this report an assessment of Mars ascent capsule weight is undertaken which combines inputs from the McDonnell data as well as studies performed if a comparison with mercury was not justifiable due to a marked departure in mission requirements.

The preliminary portion of this memorandum describes a nominal MEM mission profile and cites the general ground rules upon which the weight allocations were predicated. Also, comparisons of MEM/AS with the LM and Apollo CM are discussed. The purpose is to highlight the basic differences between these spacecraft and MEM/AS which make them comparatively poor candidates for MEM/AS scaling comparisons.

Mission Profile

The MEM arrives in the vicinity of Mars with an Orbiter mission module which, via retropropulsion or aerodynamic braking, establishes a highly elliptical (24 to 48 hour) capture orbit with periplanet velocity slightly below escape, i.e., at about 16,000 fps. This orbit is non-optimum for MEM/AS ascent, but is desirable to minimize main module braking and return injection velocities. The MEM separates from the parent ship and descends to the surface either by direct entry (prior to the capture maneuver) or from elliptical orbit by aerodynamic braking and retropropulsion. An arbitrary staytime, perhaps 30 days, is provided during which time surface reconnaissance and experiments are performed. The astronauts return in the ascent stage and rendezvous with the parent module in elliptical orbit.

Abort capability is provided prior to entry, for a period of time shortly before touchdown and from the surface in the event of surface shelter failure.

The MEM descent vehicle is a cone or Apollo shaped entry shell which contains heat shield, retropropulsion, landing gear, the return stage, and perhaps a laboratory and shelter for surface operations (since the latter two items can, alternately, be delivered in a separate vehicle). The return stage houses descent command system control interfaces, the ascent capsule, and return propulsion stages. Abort on entry necessitates that the astronauts ride in the ascent stage to allow rapid escape.

The relatively heavy entry landing systems (i.e., computors, guidance, and communications subsystems) are packaged in the descent stage and connected to the ascent/command capsule by umbilicles (or an inductance couple) capable of being broken immediately in case of abort launch.

[redacted]

Surface and abort launch are achieved via preprogrammed trajectories to low circular orbit. A single orbit coast (or less) is allowed for positioning and orbit determination from the main module via high gain antenna. Transfer is achieved so that the MEM/AS is slightly ahead of the parent spacecraft. Initial separation is not more than several 10's of miles, and closing steadily. The MEM/AS is guided by radio command from the main module during the final phases of the rendezvous sequence. At rendezvous, the astronaut either flies the MEM/AS into a prepared docking area, or leaves the spacecraft and maneuvers to the main module by EVA. A nominal mission then requires an astronaut to live in the ascent stage for perhaps 6 hours before landing and 1 or 2 hours after ascent.

Why Mercury and Not LM or Apollo CM

Preliminary scaling estimates indicate the MEM ascent payload growth factor (ratio of gross weight to payload) is about 24 compared with a descent payload growth factor of less than 3. This gives an 8/1 ascent/descent "sensitivity" ratio which is a good measure of the relative degree that each subsystem governs MEM gross weight. It is evident from the sensitivity factor that minimizing the ascent stage weight, even at some expense to the descent stage, ultimately results in the minimum MEM gross weight.

Lunar Module Scaling: Similar ΔV scaling exercises for LM, however, suggest that in a lunar mission a completely different design philosophy is preferred, and that is to minimize total i.e., ascent plus descent dry weight.

The absence of aerodynamic braking results in matched descent and ascent ΔV's giving a 2 to 1 sensitivity ratio. It is difficult (principally because of reduced packaging efficiency) to save a pound of ascent dry weight without expending at least 1 1/2 to 2 pounds of descent weight in the process, thus effectively cancelling any advantage in the LM design approach for MEM/AS. Design simplicity determined that the LM ascent stage support the combined functions of the command center, surface shelter, and ascent and descent crew quarters.

The conclusion is that in view of the marked differences in the sensitivity ratio LM is a poor candidate for a MEM/AS systems design comparison.

Apollo CM Scaling: The Apollo CM performs command functions which are analogous to the main module in scope, rather than MEM/AS. The enormous complexity of the command/earth ascent/reentry/abort role Apollo plays makes it difficult to assess specific system tradeoffs for a MEM/AS scaling comparison.

Mercury/MEM/AS Comparison

Simplicity of design and operation make Mercury the most logical candidate for MEM/AS scaling.

Consider that the ascent capsule is designed solely to provide transportation from the surface of Mars to a parent module in parking orbit. No experiments are performed en route, communications and telemetry are minimal, and there are no operations that require man's functional mobility, so high volumetric efficiency can be achieved. In fact, design and environmental constraints imposed on MEM/AS are, in many respects, less severe and less complex than those of Mercury. For example, nominal return flight time from (Mars) surface launch through rendezvous is on the order of 2 hours with between 4 to 12 hours for emergency contingency, compared to a three day flight time for Mercury. The time factor alone suggests that considerable reduction in MEM/AS consumables, power, stability and control, and life support subsystem can be achieved.

As another example, the ascent stage is to ride inside a descent/landing capsule during Mars entry and is, therefore, completely protected from aerodynamic loads and heating. As a consequence, the heat shield and backup structure required for Mercury are eliminated and the aero shell is considerably lightened. Entry penalties, costly in added stability control and guidance contingencies can, therefore, be discounted.

Mercury Weight Breakdown

Before entering further discussion, it is necessary to consider the Mercury weight breakdown so as to appreciate what the constituents of the commonly quoted 4600 lb gross launch weight are.

The Mercury weight breakdown is as follows:

Item	Weight (lbs)	Comments
Structure	615	Includes 75 lb couch
Adapter-Capsule to Booster	200	Jettisoned prior to entry Consumables compartment
Escape	1119	Escape tower
Heat Shield	315	Other thermal environment penalties in structures
Stability & Control Systems	306	Completely redundant automatic and manual control
Retrograde Propulsion	317	Entry ΔV
Landing Systems	320	Chute, Floats etc.
Instruments & Navigation Equipment	77	
Electrical Group	510	Power 390 lbs, Electrical 120 lbs
Communications	119	Gemini 60 lbs
Environmental Control & Life Support	248	
Telemetry and Recording	116	
Recovery Gear	23	Parachute, floats, etc.
Crew and Survival Equipment	261	
Experiments	51	
Ballast	0	
Gross weight	4600	

The weights in orbit and at recovery are, by comparison, 3266 lbs and 2418 lbs, respectively.

The surface abort and aerodynamic reentry phases of the Mercury mission sequence, are eliminated in MEM/AS. The consequence of these differences is significant. Mercury included an escape tower to house a high thrust propulsive unit which weighed 20% of the total Mercury launch weight. Besides the basic escape system weight, considerable structural penalty resulted from added loads on the body structure during earth launch.

Entry systems, including heat shield, retrograde propulsion, and landing subsystems, can be discounted in the MEM/AS design for another 20% reduction.

As suggested from the discussion of the mission profile the following items may be immediately eliminated:

Escape	1119
Heat Shield	315
Retrograde	317
Landing Systems	320
Recovery Gear	23
Experiments	51
TOTAL	2145

This is 47% of the gross weight at launch.

Additional Mercury Design Penalties

In the initial design of the Mercury spacecraft, two guidelines were firmly established, (1) to use existing (1959) technology and off-the-shelf equipment whenever practical, and (2) to follow the simplest most reliable approach to system design. Also, there was no information pertaining to man's capability to operate under space environmental conditions, particularly weightlessness.

In the course of discussion it becomes evident that, as a result of these factors, a substantial penalty is accrued from numerous redundancies and oversimplifications which for the most part can be eliminated in a well tested MEM/AS system.

Rather than allocate a contingency for each item discussed, 20% of MEM/AS gross weight (excluding crew and crew support equipment) is alloted for small systems backup and bypass components.

Life Support

The MEM/AS nominal return mission is approximately 2 hours from launch to rendezvous, hence a 12 hour capability provides ample reserve. It is questionable whether (as in Mercury) both a space suit/backpack and an onboard environmental control/life support system are necessary for a mission of such short duration.

Consider that the present Apollo space suit/backpack system will enable an astronaut to leave the LM for a four-hour lunar excursion, during which time no redundant spacecraft environmental control backup system will be available. While on the lunar surface adequate redundancy must be provided by the backpack.

The current Apollo backpack weighs 68 lbs of which 48 lbs is dry weight. (The package dimensions are 26" x 17" x 10" for a volume of 2.6 ft^3.) In discussions with Hamilton Standard personnel (Reference 1) it is estimated that with advanced technology (i.e., currently under development) a "12-hour" backpack will be achieved for the present "4-hour" backpack weight, i.e., at about 70 lbs. For the present it is assumed that in operation, the backpack weight increases to 100 lbs and the volume increases by about 1 ft^3.

Estimating a total of 100 lbs (currently state-of-the-art) for life support and 40 lbs for a space suit, a total of 140 lbs is required. It is believed that a redundant ECS/LS system is unnecessary. Accordingly the 248 lb Mercury environmental control system is eliminated in the MEM design.

Furthermore, it is important to consider the environmental differences between the lunar surface and that of the ascent spacecraft cabin. The lunar surface imposes a light/dark (or sun/shade) design temperature differential of over $\pm$ 200°F. Passive thermal control in the spacecraft cabin should reduce this nearly an order of magnitude.

A classic example of passive spacecraft thermal control is the Orbiting Astronomical Observatory which maintains tolerances to less than several tenths of a degree. The ascent capsule does, however, have the additional problem of maintaining thermal control throughout launch. Preliminary calculations indicate that aerodynamic heating and dynamic pressures during ascent through the tenuous Martian atmosphere is quite low. Light weight insulation, or, for that matter, a plastic shroud should provide an adequate thermal barrier to protect both men and instruments from the severest temperatures and temperature gradients experienced during ascent.

An important offshoot of this is that the spacecraft cabin does not have to be pressurized or sealed to the outside environment. (The cabin is considered as a separator rather than a pressure vessel.) The result is a substantial reduction in the weight of the spacecraft skin since in spacecraft design a double shell is required in all pressurized areas to safeguard against cabin pressure loss and to reduce leakage rates.

Structures

The marked differences in structural design constraints for Mercury and MEM/AS are a result of several interacting factors which may be classed in the two principal groupings of 1) loads, and 2) configuration.

Loads

Table 1 summarizes the fundamental differences in design loads for the two systems.

The Mercury structure consisted of a capped, truncated conical shell which served both as a pressure vessel to house the astronaut, and an an equipment bay. Aerodynamic and launch loads on the shell, aside from the bending moments induced by the escape tower, were columnar and compressive. Skins were constructed of minimum gage .010 inch material at unpressurized wall sections and all pressurized areas were fabricated with double skin construction. Pressure bulkheads were at the front (fire-wall) and rear of the cabin. The front bulkhead was an elliptical dome with double skin construction and extensive cross patterns of stringers which provided added structural integrity.

The significant structural changes between the Mercury design and a MEM/AS capsule are:

1. Elimination of all double layer construction required in pressurized areas,

2. Elimination of escape tower support structure,

3. Substantial reduction of front bulkhead skin and stiffeners,

TABLE 1

Comparison of Mercury and MEM/AS Design Loads

Condition	Mercury	MEM/AS
Test	14 psi pressure differential	Zero pressure differential
Earth launch	launch/7g's Escape Tower loading Aerodynamic loads	launch/7g's
Free Space	5 psi pressure differential Thermal	Thermal
Reentry	reentry/15-20g's aerodynamic pressure aerodynamic heating	----
Mars Entry	----	10g's "Cradel" support in descent stage (i.e., redundant supports throughout peak g phases)
Mars Ascent	----	Low aerodynamic pressure Low aerodynamic heating Launch/1 earth g Docking
Recovery	Chute Bridle Shock Water recovery	----

4. Elimination of recovery bay structure , and

5. Reduction of stringer and longeron structure by approximately 50%.

The Mercury structure weighed 650 lbs. Reviewing a detailed computer weight breakdown which included a listing of all structural elements, McDonnell personnel* estimate that a Mercury capsule designed to the above conditions would weigh approximately 250 lbs. This figure was arrived at by consideration of the entire structural assembly. An example of one of the more significant changes is the astronauts couch. The Mercury couch weighed 75 lbs. McDonnell estimates that today a couch meeting the same specifications can be built for 15 lbs.

Configuration

The Mercury configuration is governed by reentry and aerodynamic launch constraints, whereas the MEM/AS can be more closely tailored to optimum packaging requirements. The conditions that must be considered in the MEM/AS design are:

1. Mars entry,

2. Pre-landing abort,

3. Surface touchdown, and

4. Mars launch.

Abort necessitates the astronaut descending in the ascent capsule and, consequently, the astronaut must be constrained to a supine condition to withstand peak entry g's.

Surface touchdown in a possibly hostile environment and rugged terrain makes it necessary that the astronaut have a clear, unobstructed view of the landing area. This requirement can be accommodated at a minimum weight penalty by employing landing TV on the descent stage. The field of view is monitored by the astronaut via high resolution orthicon inside the ascent capsule. The orthicon can also be used to monitor other landing subsystems which, to achieve ascent weight economy, are mounted in the descent stage and piped to the ascent capsule display. The umbilical connecting the two sections is automatically severed at launch or abort.

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*J. J. Moran, W. Ready and J. Windham.

With remote viewing, the ascent capsule can be completely encased in the descent stage, so that protection from entry heating and aerodynamic loading can be provided.

Mars launch imposes little in the way of physiological constraints since the loads are quite low (less than 1 earth g) and the time spent in the capsule is relatively short. However, since the astronaut constitutes a considerable portion of the spacecraft weight, the controls problem makes it expedient that the astronaut be essentially motionless during the ascent and rendezvous thrust phases.

In view of these considerations, it is estimated that the wetted area of the Mercury capsule can be reduced from 118 ft^2 to approximately 92 ft^2, with a corresponding scaled reduction in structural weight. The prorated structural weight is thus on the order of 200 lbs or 2.2 lbs/ft^2. This is hardly unconservative in view of the improved strength to weight of composite materials which should become available by the early 1970's. Furthermore, this structure has not been optimized with respect to an ascent stage configuration. The aerodynamic shroud for example would weigh somewhat less than 1 psf if advanced plastic composites were employed.

Adapter

The Mercury adapter serves as an equipment bay for consumables and retropropulsion, which along with the adapter, are jettisoned before reentry. MEM/AS does not make provision for this type of structure since consumables are small by comparison to Mercury, and no retropropulsion is required.

Communications

The Mercury communications weight is 119 lbs with the subsystem breakdown as follows:

Item	Weight (lbs.)
HF & VHF	22
S&C Band Tracking	33
Command Receiver	13
Common Units & Switching	13
Structure Support and Brackets	32
	119

This weight was halved in Gemini to 60 lbs. The major portion of this savings was achieved through solid state circuitry and miniaturization.

The MEM/AS communications system is a marked departure from that of Mercury and Gemini. The latter flights were designed to allow in situ evaluation of basic scientific and physiological phenomenon, and to develop man's operational capability. Achievement of these goals was enhanced by an extensive, real time interplay between spacecraft personnel and control centers for which an elaborate communication system was provided.

During Mars entry, landing and prelaunch preparations, extensive communications between MEM and the parent module is desirable. This is provided by a relatively elaborate communications system on the descent stage, at little gross weight penalty. Such a system would, however, be quite costly aboard the ascent stage, and, moreover, is not clearly warranted. The parent module has substantial down link capability which is provided by a 20 to 30 ft onboard antenna. It is, therefore, possible to receive continuous down link commands to which MEM/AS can respond whenever necessary via a small omni-directional antenna. An up range "interrogation" or Code link should provide adequate exchange for command decisions. A selective up range voice link can, however, be provided at minor penalty. In this regard the following is quoted from Reference 2, prepared by R. H. Chen of Bellcomm:

> "A Communication system using existing design has (in Reference 2) been outlined for the Ascent and Rendezvous phases of a manned Mars landing mission. The system is sized to provide coherent range and range-rate tracking and two-way voice/data functions. It was found that the addition of the two-way voice/data capability to the system would require 10 watts of RF power transmitted from the Manned Ascent Module compared with the one watt RF power requirement without this capability. By utilizing the available communication equipment (five pounds) in the (current Apollo) backpack it is determined that the weight addition needed to implement the two-way voice/data is less than two pounds."

Therefore, in the selected MEM/AS design, extensive communications capability is provided in the descent stage. The "ascent" communications system is similar to the minimum system described above. Estimating 2 lbs for communications and 3 lbs for the umbilical and distribution system the ascent communications weight is 5 lbs.

Telemetry and Recording

During MEM/AS ascent and rendezvous there is no need for telemetry transmission other than to monitor environmental and control system data for possible post mortum analysis, i.e., to disclose the nature of ascent vehicle failure if failure should occur. All information transfer during descent is to be accomplished via the descent stage communications/ telemetry link.

The Mercury mission, by comparison, required extensive telemetry transmission since the performance of all subsystems (especially man) were of interest. A substantial contingency was allocated for instrumentation which can be almost completely discounted in the MEM/AS design. The Mercury weight summary is as follows:

Camera (Pilot)	7
Camera (Instrumentation)	8
Telemetry Transmission, Power and Programmers	9
Recorder	14
Biomedical Instrumentation	14
Environment Instrumentation	4
Distribution System	51
	116

In comparison of the 116 lb Mercury T&R weight, that of MEM/AS is estimated to be about 10 lbs. This includes 3 lbs for instrumentation and 7 lbs for the distribution system.

Instrumentation and Navigation

The instrumentation and navigation group includes computers and displays for monitoring environmental systems status data, and sequencing events.

The weight of the Mercury package totals 77 lbs. McDonnell estimates that this weight could currently (on an item by item basis) be reduced to less than 50 lbs.

A fundamental change in design philosophy could, however, result in further marked improvements. For example, by employing a currently available off-the-shelf, "integrated" display this weight would be reduced by more than half and yet accommodate all MEM/AS display and computer requirements. Here all channels are fed directly to a single computer and called by keyboard command. The weight of a specific computer package,* including 8000 word storage capacity, decimal display, keyboard, and 24-hour power supply, is 12 lbs (this storage capacity compares with 12,175 words for Gemini). Allowing 8 lbs for the distribution system, and hookups to the telemetry and communication networks, a total weight of 20 lbs is estimated. (By comparison the Mercury clock alone weighed 8 lbs.) The display readout could include temperature, pressure, voltage, time, and general systems status data.

[As a point of philosophy it is not clear that <u>any</u> displays are warranted onboard the MEM/AS. Presumably all telemetry can be sent via communications link directly to the main module where it is to be monitored and, if necessary, sent downrange. The basic question to be answered is, can the astronaut take effective action predicted on display data? It may be noted that displays are not carried on parachutes.]

<u>Stability and Control</u>

Mercury S&C weight totaled 206 lbs which includes completely redundant manual and automatic controls, and a redundant reaction jet system. The weight breakdown is as follows:

Item	Weight (lbs)
Manual Controls	26
Electronic & Block Boxes (Guidance)	81
Primary and Redundant Propellants (2 @ 30 lbs)	60
Propellant Inerts (2 @ 60 lbs)	120
Miscellaneous	19
	306

*Control Data Corporation/Miniature Portable Computor System.

RJS Propellant was Hydrogen Peroxide (H_2O_2). The propellant inerts include 24 pitch and yaw thrusters, 6 roll thrusters, and all propellant containers and plumbing. Approximately half of the RJS propellant weight was provided for reentry as was a considerable portion of the electronics (guidance) package.

Substituting present state-of-the-art Hydrazine monopropellant ($I_{sp} \sim 230$) in lieu of H_2O_2 ($I_{sp} \sim 160$), a propellant weight reduction of 31% can be achieved on the basis of the improved specific impulse. Furthermore, Hydrazine affords a significantly improved inert to propellant ratio because of the substantial decrease in catalist bed weight. As compared to 2 lbs of H_2O_2 inerts per lb of propellant in Mercury, it is estimated that only one pound of inerts would be required per lb of Hydrazine. Matching the performance of the Mercury RJS system, these modifications result in 42 lbs RJS weight as compared to 90 lbs for the H_2O_2 system.

Mercury (in orbit) inertia is approximately four times that of MEM/AS. Discounting an additional factor of one half for the reentry propellant allocation, ACS propellant weight is reduced by a factor of 8, and weighs approximately 3 lbs. Rendezvous propellant must be included to determine the complete SC subsystem weight.

Rendezvous

MEM/AS rendezvous occurs during the outbound leg of the highly elliptical (main module) orbit where angle and plane change correction sensitivities are low. Moreover, seven hours are available for closure from the time of initial orbit transfer to rendezvous. Consequently, the required rendezvous ΔV budget is quite small. 100 fps is a conservative estimate of the velocity change required. Based on 100 fps and a MEM/AS weight of 800 lbs, the RCS propellant weight for rendezvous and ACS is 14 lbs. Propellant inerts weights are estimated to be 1.25 lbs per lb of propellant for this propellant weight, so that total inerts weight is 18 lbs.

Guidance

This electronics group includes guidance packages and related subsystems for which the combined Mercury weight is 80 lbs.

The mission sequence for MEM/AS is markedly different from Mercury so that before a subsystem comparison can be undertaken many qualifying factors must first be considered.

It is presumed that all MEM/AS entry guidance systems are carried on the descent stage. Also, the ascent propulsion stage is to contain a separate guidance package preprogrammed for abort (i.e., return to circular orbit) during the entry sequence. After landing, this same guidance package can be reprogrammed for surface launch to the low circular coast orbit. Surface launch programming commands are given by the parent module operating in conjunction with the landed descent stage.

As the ascent stage achieves coast orbit (either by abort or surface launch) the MEM/AS guidance system assumes control. Coast time in circular orbit is sufficient to allow for positioning and orbit determination during which time corrections are calculated onboard the parent module and relayed by radio command.

Transfer from the low circular to elliptical orbit rendezvous is controlled from the parent module via radio command guidance. The MEM/AS onboard guidance package is a strap-down system consisting of three integrating gyros. Integration is controlled via the parent module to establish transfer and rendezvous corrections. This package has been considered for unmanned Mars Surface Sample Retriever (MSSR). In reference 3 the MSSR package extended to a manned ascent stage guidance system is estimated to be 5 lbs. Employing three packages for redundancy,* the MEM/AS guidance weight is 15 lbs.

In summary, the revised weights for the MEM/AS S&C system are:

ACS & Rendezvous Propellants	14
Propellant Inerts	18
Guidance, Electronics	15
	47

*For purposes of this study such redundancy is warranted in view of the advanced state-of-the-art of this system.

Electrical/Power Group

The Mercury Electrical/Power group weighed 510 lbs. Of this 120 lbs was for the electrical system, 340 lbs for primary power, and 50 lbs for a separate squib, i.e., disconnect system.

The electrical system breakdown is as follows:

- inverters AC-DC	24
- distribution (highly redundant heavy, gage shielded wiring)*	92
- lighting	4
TOTAL	120

The distribution weight can be reduced by a factor of two with currently available light weight "flat-edge" wiring. By direct elimination of Mercury subsystems in the MEM/AS at least an additional 70% reduction can be achieved. On this basis, MEM/AS electrical system weight is approximately 20 lbs.

The Mercury power system consisted of eight 42 lbs (each) silver-zinc batteries, each rated at 3000 w hrs, supplying 24,000 w hrs for the entire mission. The specific power average is approximately 70 w hr/lb. which is perhaps 10%-20% less than the current state-of-the-art. Prorating the power requirements on a time basis yields a power reduction factor of 12/72 or .17 (based upon the 3 day Mercury mission). In view of the elimination of ECS and reentry systems, and reductions in telemetry, communications, and numerous other subsystems, this power factor estimate is quite conservative. A minimum 1/3 power reduction on a per unit time basis for MEM/AS (particularly a result of reduced prime communications power needs) is appropriate. Coupled with an estimated 10% specific power increase based on current technology (it is presumed that ascent stage batteries are activated at abort or immediately prior to surface launch) the resulting weight fraction is 10% of Mercury's, or 34 lbs and which yields a total power supply of 2600 w hrs.

Major Mercury squib (or separator) system weight penalty is incurred at the adapter, retropropulsion and landing systems interfaces. In MEM/AS the only major separation plane occurs at final staging for which 5 lbs is allocated.

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*It is interesting to note that the total weight of wiring for combined Mercury subsystems was 500 lbs.

The total MEM/AS electric power group weight is therefore estimated at 59 lbs.

MEM/AS Weights Summary

The weights summary for the MEM/AS capsule based on previous discussions is shown in Table 2. Allowing 20% of systems weights excluding crew, crew systems, and payload, for small systems backup and bypass contingencies the total weight is 738 lbs.

Two-Man Capsule Scaling Comparison

The ratios of Gemini/Mercury wetted area and diameter are 1.80 and 1.25 respectively. The subsystem weight of a two-man vehicle, as derived from these scaling factors, is given in Table 3. The total vehicle weighs an estimated 1360 lbs.

Conclusions and Comments

Upon careful scrutiny, the 4600 lb Mercury launch weight diminishes markedly when tailored to the suggested ground rules and constraints of the manned Mars return capsule.

It is concluded that upon elimination of Mercury design constraints consistent with a Mars ascent capsule mission profile (i.e., reentry, surface launch abort capability, and life support redundancy) the weight of a "derivative" Mercury spacecraft is reduced from 4600 lbs. (at launch) to under 800 lbs. Advances beyond the current state-of-the-art have not been included to achieve these reductions. Employment of advanced systems coupled with refinements in operational procedure would undoubtedly result in substantial added weight reductions.

Some of the more important implications of these results are:

1. One-man MEM ascent capsule weight seems to be compatible with MSSR launch capability to a highly elliptical capture orbit, and

2. A two-man MEM of less than 35,000 lbs. gross weight appears to be feasible.

1013-MHS-jdc M. H. Skeer

Attachments Figures 1 - 3
References

TABLE 2

MEM/AS Useful Load Weight Breakdown

Item	Weight (lbs)
Structure	200
Stability & Control/Rendezvous	47
Instrumentation & Navigation	20
Electrical/Power Group	59
Communication	5
Telemetry	10
Crew Systems	140
Crew	170
Payload	20
Contingency for Redundancies	67
	738

TABLE 3

Two-Man MEM/AS Useful Load Weight Breakdown

Item	Weight (lbs)	Comments
Structure	396	1.8 W(1)* + 10%
Stability and Control	101	2 W(1) + 10%
Instrumentation & Navigation	22	W(1) + 10%
Electrical/Power Group	65	W(1) + 10%
Communications	5	
Telemetry	11	W(1) + 10%
Crew Systems	280	2 W(1)
Crew	340	2 W(1)
Payload	20	
Contingency for Redundancies	120	
	1360	

*W(1) = one man ascent capsule subsystem weight

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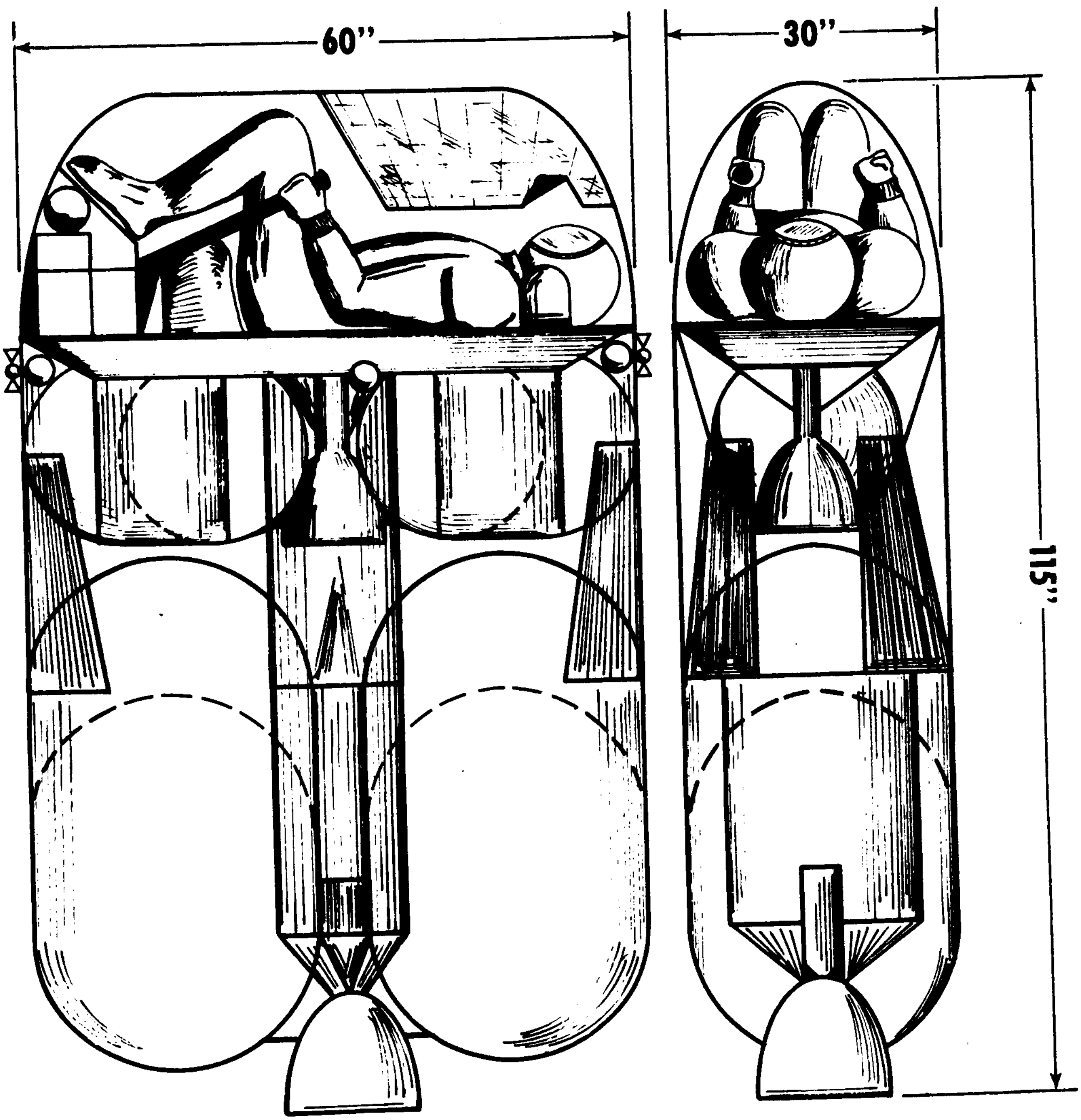

FIGURE 1 - MINIMEM/ASCENT STAGE

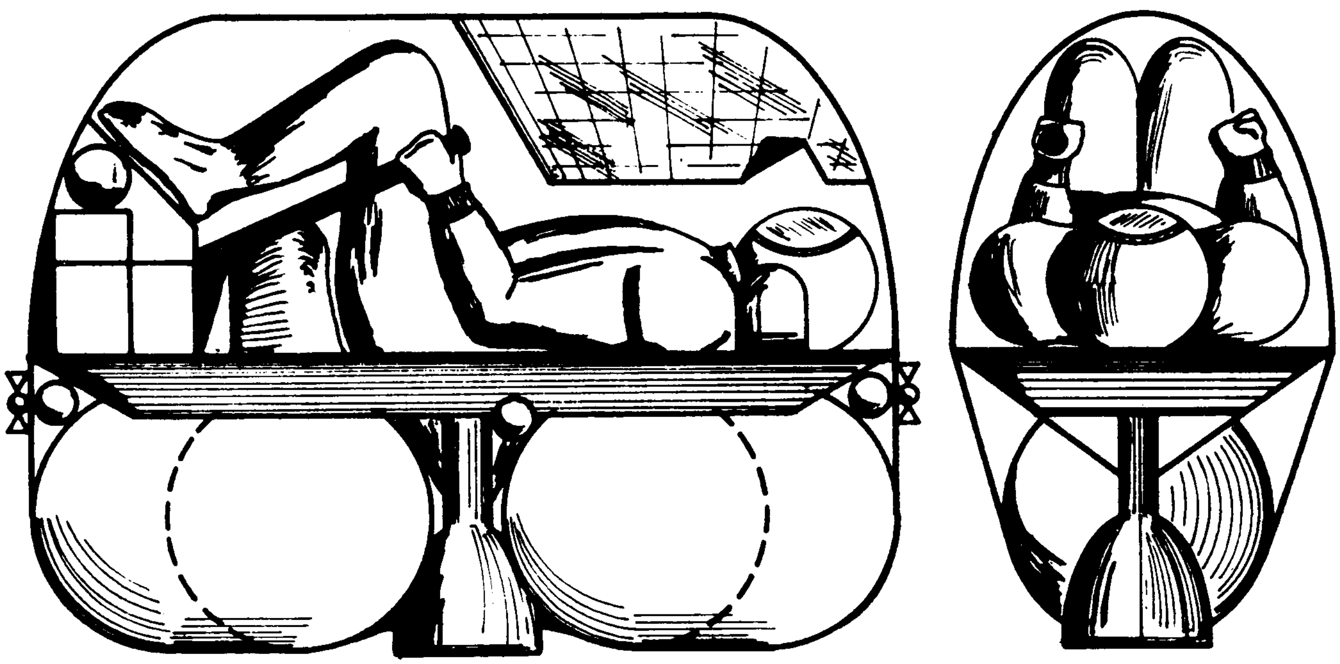

FIGURE 2 - MINIMEM/CAPSULE AND SECOND STAGE

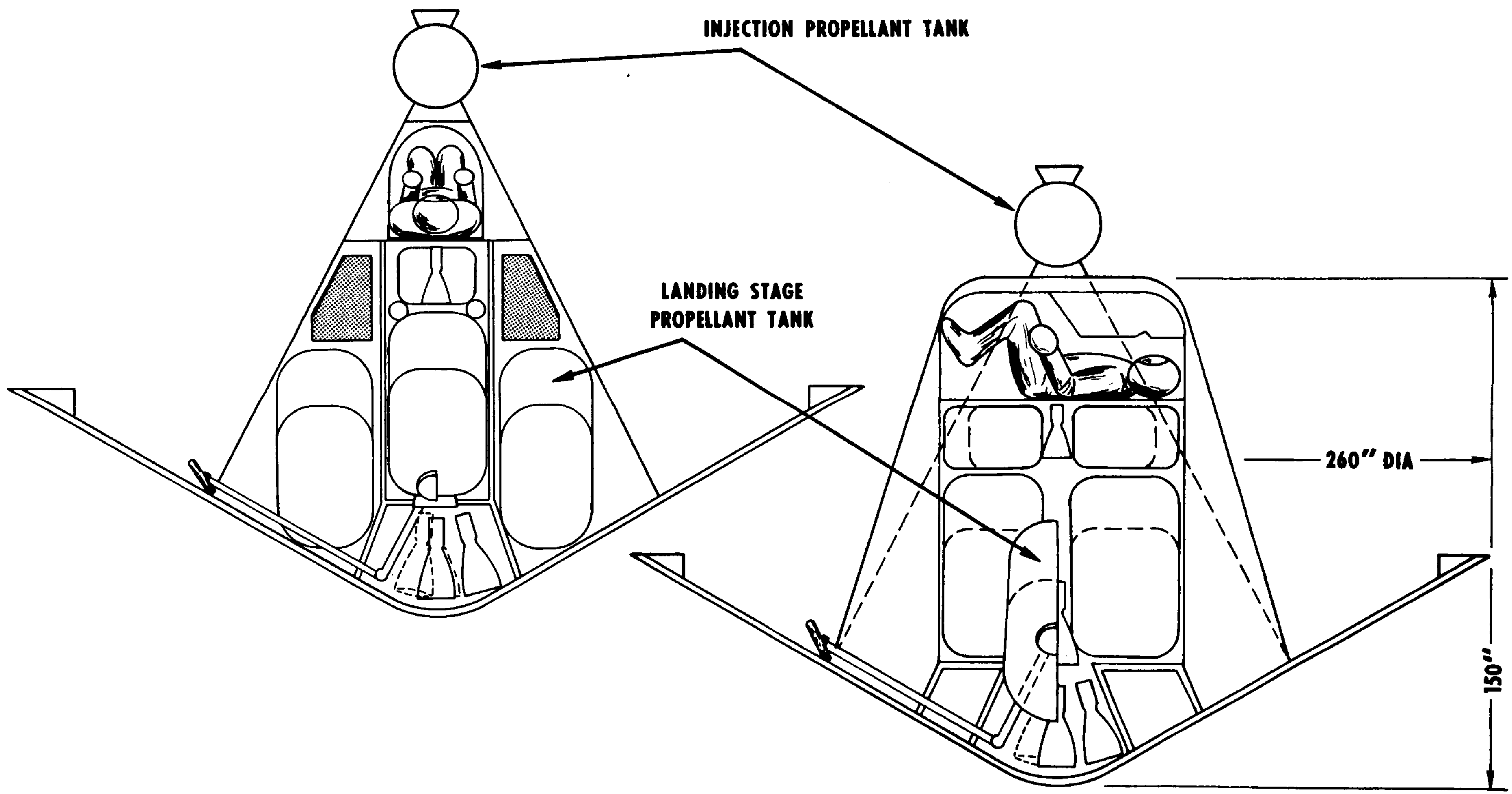

FIGURE 3 - MINIMEM GENERAL ARRANGEMENT ENTRY CONE CONFIGURATION

BELLCOMM, INC.

Subject: Preliminary Sizing of a Mars Excursion Module Ascent Capsule Based on Mercury Spacecraft Design
Case 233

From: M. H. Skeer

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